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Multi-RFID embedded Ticketing Kernel for MaaS

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Resumo

O aumento da população e do êxodo rural tem aumentado significativamente, demonstrando cada vez mais a atual tendência universal de hiper-urbanização e globalização. Simultaneamente, a popularização do uso de carros particulares para deslocamentos diários, contribui para diversos problemas ambientais e de saúde, como por exemplo, os elevados níveis de ruído, o congestionamento e a poluição nas áreas urbanas. Maioritariamente, a concentração de pessoas nas cidades deve-se ao facto de a população ativa desejar estar mais próxima dos seus locais de trabalho, de modo a evitar longas deslocações diariamente. Consequentemente, a maioria das cidades está a simplificar e melhorar as viagens regulares e ocasionais, promovendo o desenvolvimento dos transportes.

Persiste assim a exigência de um sistema de mobilidade inteligente e seguro, que unifique todo o processo de acesso aos transportes. Todavia as seguintes questões mantêm-se, “Quais são os problemas que os passageiros experienciam? E como podem esses ser resolvidos?”. Diversos autores, que estudaram a problemática, mencionam problemas como o tempo de espera despendido em estações e paragens, o saldo não reembolsável, a falta de lugares disponíveis, o tempo necessário para obter bilhetes, o uso excessivo de papel e os problemas que daí advêm, e também a existência de pagamentos em espécie. Conclui-se então que a sustentabilidade dos transportes é o principal fator que estimula o desenvolvimento dos mesmos.

Diante destas problemáticas várias dúvidas emergem para o futuro. E ainda, surgem preocupações, de como assegurar uma organização ótima e eficaz dos transportes coletivos, públicos e privados, bem como, as alterações demográficas e socioeconômicas. Atualmente, as redes de transporte urbano fazem parte da vida diária de milhões de pessoas em todo o mundo. Na era da digitalização, dos serviços e da economia sem transações físicas, os transportes públicos também devem ser reajustados. Portanto, os cartões bancários *contactless* farão com que seja razoável viajar de transporte público. Será a primeira vez em Portugal que um cartão bancário *contactless* permite o acesso, a deslocação e o pagamento dos transportes públicos. Tal solução encorajará a que o cartão de débito ou crédito *contactless* seja uma alternativa ao cartão proprietário dos transportes, permitindo assim melhorar a usabilidade e acessibilidade dos transportes públicos.

Em todo o mundo, e tendo em mente a problemática existente, vários países têm tentado encontrar novas soluções mais convenientes para os passageiros, e também para

melhorarem as transações econômicas nos seus atuais sistemas de bilhética. Muitos deles instauraram soluções de pagamento *contactless* estabelecidas na emissão de bilhetes com base em contas de utilizador, e fazendo uso dos cartões bancários dos passageiros, pois desta forma os serviços de transporte podem oferecer viagens melhores, mais convenientes, e de fácil e rápido acesso. Assim, com o lançamento desta solução que suporta o uso de cartões bancários *contactless* nos transportes, uma área metropolitana portuguesa vai muito bem integrar uma lista crescente das principais cidades do mundo a inovar na indústria dos transportes, como Londres, Singapura, Rio de Janeiro e Nova Iorque.

Além disso, novos passageiros serão facilmente atraídos e integrados na utilização dos meios de transporte público, libertando-os da necessidade de manterem um carro particular com todas as despesas inerentes. Isto permite assegurar uma mobilidade mais sustentável e indiretamente diminuir a emissão de gases poluentes, o ruído constante, e também o fluxo do trânsito nas zonas urbanas.

Embora o progresso no setor dos transportes e o aparecimento de novos serviços de transporte seja satisfatório, Portugal ainda está muito desatualizado em relação aos demais países. Dado que as operadoras de transporte não têm uma solução global para abordar os sistemas de bilhética de uma forma única e comum a todas elas. Assim, o objetivo deste projeto era o desenvolvimento de um sistema baseado em contas de utilizador, que permitisse pagamentos *contactless* e pós-pagos, utilizando cartões de débito ou crédito, e integrá-lo nos atuais sistemas de bilhética dos transportes.

Este trabalho permitiu desenvolver uma aplicação de pagamentos inserida no EMV Level 3 interoperável, que foi posteriormente integrado num *middleware* de bilhética transversal que constitui os atuais validadores/terminais dos transportes. A interoperabilidade era um requisito crucial na implementação deste módulo, visto que este deve ser independente de qualquer *hardware* existente, de forma a reutilizar os validadores no setor dos transportes. Foi ainda exequível, na ótica de prova de conceitos, estudar e desenvolver um módulo de software, denominado Kernel 3 (Visa PayWave), que implementa um conjunto de funções que fornece a lógica de processamento e os dados necessários para realizar uma transação EMV *contactless*. O Kernel 3 insere-se no EMV Level 2, e constitui o correto funcionamento das aplicações EMV Level 3.

Este projeto pioneiro em Portugal envolveu vários *stakeholders*, incluindo a Card4B Systems (Card4B), a Littlepay, a Visa e a Unicre. O projeto teve como objetivo fornecer uma aplicação com um modelo de circuito aberto para pagamentos *contactless* e pós-pagos, que visava integrar as atuais operações de emissão de bilhetes de transporte. Por fim, a solução desenvolvida suporta transações *contactless* e assegura a máxima segurança das mesmas, pois seguiu as especificações “*Contactless Specifications for Payment Systems*”.

Tanto a solução desenvolvida, como a solução final integrada nos sistemas dos transportes foram certificadas com sucesso e obtiveram uma Certificação EMV Level 3 para

transações Visa PayWave e MasterCard Contactless. Ambas as aplicações foram exaustivamente testadas pela Littlepay, a entidade responsável pela certificação, utilizando uma ferramenta de testes capaz de emular cartões bancários contactless, e simular vários cenários e situações de erros de forma a testar a robustez e os requisitos da aplicação EMV Level 3. As certificações Visa PayWave e MasterCard Contactless credenciam e garantem a segurança da utilização da aplicação desenvolvida para processar transações com cartões de débito ou crédito contactless em validadores/terminais de trânsito.

Concluindo, o projeto desenvolvido em parceria com a Card4B Systems (Card4B) cumpriu com os seus objetivos de desenvolver um sistema baseado em contas de utilizador que permitisse acesso à rede de transportes com cartões bancários *contactless*, tal como pagamentos pós-pagos. Esta solução integra o sistema atual e transversal de emissão de bilhetes dos transportes, que a empresa Card4B Systems proporciona aos seus clientes. Esta empresa não só desenvolve soluções para suportar as atividades dos clientes, mas também investe em projetos de investigação e desenvolvimento, seja a nível nacional ou internacional, sendo essa uma das principais motivações para a conceção deste projeto. Resumidamente, este projeto permitiu à empresa inovar os seus produtos existentes, e ainda, proporcionar aos transportes uma solução interoperável, global, inclusiva, cômoda, simples e conveniente para os seus passageiros, contribuindo assim para o desenvolvimento dos sistemas de bilhética dos transportes públicos e privados em Portugal.

Isto posto, os operadores dos transportes públicos comprovam assim uma diminuição dos seus pontos fracos, pois os cartões proprietários passam a ser emitidos e geridos pelas instituições financeiras. As vantagens incluem uma redução dos custos operacionais, como permitem as agências de transporte direcionarem a sua atenção para aquele que é o foco do seu negócio, i.e., transporte coletivo, viagens multimodais, e cálculo das tarifas. Por outro lado, os passageiros podem esperar também uma maior comodidade, permitindo-lhes utilizar o seu cartão bancário *contactless* agora multifuncional, ao invés dos diversos cartões proprietários dos vários transportes que frequentam. Além disso, os bancos desfrutam também de vários benefícios do desenvolvimento de sistemas de pagamentos em circuito aberto no setor de transportes. Por exemplo, a colaboração com as agências de transportes coletivos introduz a partilha de dados adicionais sobre os seus clientes, o que possibilita às instituições financeiras a elaboração de análises dos padrões de comportamento dos seus clientes, e assim conseguirem presentear-los com ofertas personalizadas. Finalmente, embora indiretamente, esperam-se benefícios ambientais a longo prazo, como a redução das emissões de carbono, do congestionamento do trânsito e da poluição sonora, e ainda uma diminuição no desperdício de papel e no uso de plástico.

Palavras-chave: inovação; transportes; pagamentos *contactless*; sistemas de bilhética; cartões bancários.

Abstract

The fast-growing human population is causing an ever-increasing trend of hyper-urbanisation and globalisation, along with the popularisation of private cars to commute, which contributes to several environmental and health problems, for instance, high levels of noise, congestion, and pollution. Hence, most cities are facilitating and enhancing commuting travel, thus, fostering the development of transportation.

Today's urban transport networks are part of the daily lives of millions of people around the world, and in this era of digitalisation, servicing, and cashless economy the public transportation must also readjust. Therefore, contactless bank cards will make it reasonable to travel by public transport. It will be the first time in Portugal that a contactless bank card enables public transport to be accessed, travelled and charged. Such a solution would encourage the contactless debit or credit card to be an alternative to the proprietary transit card, thereby helping to enhance the usability and accessibility of public transport.

With the launch of the contactless solution in public transport, a metropolitan area in Portugal will very well integrate a growing list of the world's major cities such as London, Singapore, Rio de Janeiro and New York. Moreover, new passengers gradually shift from maintaining a private car to the use of public transport means, which allows a diminution on the emission of fuel gases, and a reduction of the global pollution. In addition to that, public transport operators pains also decrease because proprietary cards are handled and managed by financial institutions, enabling the transport agencies to turn their attention to the core of their business, like the multi-modal mass transit and fare calculation.

This pioneering project in Portugal involved several stakeholders, including Card4B, Visa, and Unicre. Accordingly, the project aimed to provide an open-loop model with contactless and post-paid payments to integrate into the existing operation of transportation ticketing. Finally, the developed solution supports contactless transactions, and followed the “*Contactless Specifications for Payment Systems*”. Successfully, the delivered solution was certified with an EMV Level 3 Certification for both Visa PayWave and MasterCard Contactless transactions.

Keywords: innovation; transportation; contactless payments; account-based ticketing; bank cards.

Table of Contents

Table of Figures	xv
Table of Tables	xvii
List of Abbreviations	xix
1 Introduction	1
1.1 Motivation	3
1.2 Host Organisation	4
1.3 Objectives	5
1.4 Document Structure	5
2 State of the Art	9
2.1 Mobility-as-a-Service	9
2.1.1 The Concept	9
2.1.2 Core Characteristics	10
2.1.3 Business Ecosystem	12
2.1.4 Levels of Integration	13
2.2 Ticketing	14
2.2.1 Major Problems	15
2.2.2 Electronic Ticketing Systems	16
2.2.3 Automated Fare Collection	17
2.2.4 Closed-Loop Payment Systems	18
2.2.5 Open-Loop Payment Systems	19
2.2.6 Account Based Ticketing	22
2.3 Contactless Payments	24
2.3.1 Payment Methods	25
2.3.2 The Evolution of the Payment Industry	27
2.3.3 Contactless Technologies	28
2.3.4 Contactless Technologies in Transit	34
2.3.5 Contactless Payments in Transit	35
2.4 Related Work	35

2.4.1	Octopus	37
2.4.2	VIVA	38
2.4.3	Oyster	39
2.4.4	Andante	39
2.4.5	Go	40
2.5	Discussion	40
Bibliography		49

List of Figures

2.1	Comparison between the Mobility-as-a-Service model and the present mobility model	10
2.2	The Mobility-as-a-Service business ecosystem	13
2.3	Example of an RFID system	29
2.4	Architecture of an RFID reader	29
2.5	Architecture of an RFID tag	30

List of Tables

2.1	Levels of mobility integration in Mobility-as-a-Service	14
2.2	The pros and cons of open-loop payments for the major parties involved .	20
2.3	Comparison of the main characteristics of the various RFID frequencies of operation	31
2.4	Comparison of contactless technologies (HF RFID vs. NFC vs. Bluetooth)	33
2.5	Comparison of features of worldwide electronic ticketing solutions	41

List of Abbreviations

AFC Automated Fare Collection. 5, 17, 35

AICD Automatic Identification and Data Capture. 16

Card4B Card4B Systems. vi, vii, 4, 6

EMV Europay, Mastercard, and Visa. 3, 5, 6, 27, 35, 36

EMVL2 EMV Level 2. 5

EMVL3 EMV Level 3. 3, 5, 6

GIS Geographic Information System. 16

ICT Information and Communications Technology. 11, 12, 13, 36

IoT Internet of Things. 12

IT Information Technology. 9, 11, 13

MaaS Mobility-as-a-Service. xv, 2, 9, 10, 11, 12, 13

NFC Near Field Communication. 16, 25, 27, 28, 31, 32, 33, 34, 35

POS point-of-sale. 21, 25, 27, 32

RF Radio Frequency. 25, 29

RFID Radio-Frequency Identification. xv, 16, 25, 28, 29, 30, 31, 32, 33, 34

WIPO World Intellectual Property Organization. 9

Chapter 1

Introduction

The human population is developing at a fast pace causing an ever-growing universal trend of hyper urbanisation and globalisation [1, 2], due to the fact of the large concentration of people in cities, mainly to be closer to their workplace. In addition to that, the popularisation of private cars to commute helps to raise issues for the future, like the high levels of noise, congestion, and pollution in urban areas, which contributes to several environmental and health problems. Another concern is to ensure an optimal and effective organisation of urban public transport and also demographic and socio-economic alterations [1]. Therefore, these adversities act together to a significant problem related to climate change. Consequently, cities become an undesirable place to live that don't focus on the citizens' well-being. So, the city managers should progress to a greener and friendly living environment.

One approach to solve the population growth, the urbanisation, and the high demand for transportation would be to create jobs around smaller towns to disperse commuters and aid for a better lifestyle. However, since this solution may be hard to achieve, and residual problems would yet resist, another one arises, that is, facilitate and enhance commuting travel, thus foster the development of transportation.

Therefore the questions remain, what are the significant problems passengers experience? And how to solve them? Kazi et al. [3], mention issues like the time wasted waiting at stations and stops, the non-refund balance, the lack of seats, the spare time for getting tickets, the excessive misuse of paper and the concerns risen by that, also the usage of cash, in an aspiring cashless economy. As attested by Zalar et al. [4], public transport sustainability is the primary driver for public transport development.

Today's urban transport networks are part of the daily lives of millions of people around the world, and in this era of digitalisation, servicing, and cashless economy the public transportation must also readjust [3]. Hence, a requirement for a smart and reliable system subsists. The concept of smart cities could help solving the problems mentioned above [2]. But what does the term "smart" mean? The range of definitions of smart varies highly, primarily because of the context in which is applied. Often replaced

with adjectives such as intelligent or digital, the applications of this fuzzy concept aren't always consistent. So, there isn't a single agreed definition of it. Nevertheless, generally, the word refers to the adoption of new technologies and the integration of services [5] to improve well-being, high-quality life, and the environment.

Dudycz and Piątkowski present several smart city definitions in [2], one of them states the following smart cities are cities established on “smart” and intelligent solutions, and technology that lead to the adoption of at some of the succeeding parameters – smart energy, smart building, smart mobility, smart healthcare, smart infrastructure, smart technology, smart governance and education, and smart citizen. In conclusion, smart solutions are part of smart mobility, thus promoting smart cities. Despite the employment of technology in the core of smart cities, that should never be the goal but the driver.

Mobility-as-a-Service is one of the inherent concepts when mentioning smart mobility. The MaaS concept encourages the integration of multi-modal transportation into a single digital platform to provide passengers access to simple, flexible, reliable, and seamless travel. Moreover, the development of transportation conditions is vital to achieving sustainable mobility. For instance, improve the ticketing system could attract extra passengers and retain the existing ones to use public transport. Other qualitative factors, such as travel time, fare price, and travel convenience, could also be reviewed and considered with plenty of attention by transit operators.

Around the world, having in mind such problematic, several countries have tried to find out some solutions, to improve the economic transactions in the transportation sector. Many of them have started using contactless payment solutions established on account-based ticketing using the passengers' bank cards to offer a better, convenient, and seamless travel experience. Therefore, contactless bank cards will make it much simpler and quicker to travel by public transport. It will be the first time in Portugal that a contactless bank card enables public transport to be accessed, travelled and charged. Such a solution would encourage the contactless debit or credit card to be an alternative to the proprietary transit card, thereby helping to enhance the usability and accessibility of public transport.

Account-based ticketing systems operate by identifying customers using their cards to check their back-office accounts. Hence, rather than a ticket, a stored-value card or a virtual smart card hosted on a smartphone, travellers own an account in the back-office [6]. The back-office collects all the information regarding the passengers' trips history and fare transactions. This system, when aligned with contactless open-loop payments, benefits the passengers from the service's convenience because payments occur during or after the trip ends.

With the launch of the contactless solution in public transport, a metropolitan area in Portugal will very well integrate a growing list of the world's major cities such as London, Singapore, Rio de Janeiro and New York. Moreover, new passengers gradually shift from maintaining a private car to the use of public transport means, which allows a diminution

on the emission of fuel gases, and a reduction of the global pollution. In addition to that, public transport operators pains also decrease because proprietary cards are handled and managed by financial institutions, enabling the transport agencies to turn their attention to the core of their business, like the multi-modal mass transit and fare calculation.

Although the progress in the transport industry and the appearance of satisfactory transportation services, Portugal is still far behind. Therefore, transport operators lack a solution to approach the ticketing system differently. This pioneering project in Portugal involved several stakeholders, including Card4B, Littlepay, Visa, and Unicre. Accordingly, the project aimed to develop a ticketing system based on accounts and handling the passengers' contactless credit/debit bank cards to promote more convenient trips, through the implementation of an open-loop model with contactless and post-paid payments to integrate into the existing operation of transportation ticketing.

Therefore, the project comprised a software middleware capable of reading EMV contactless cards data to identify the travellers' account, validate entrances and then submit the transactions to the back-office for fare calculation and further charge request the customers' funding/bank accounts. Finally, the developed solution supports contactless transactions, and followed the "*Contactless Specifications for Payment Systems*".

Both the developed solution and the final solution integrated in the transport systems were successfully certified and obtained an EMV Level 3 (EMVL3) Certification for Visa PayWave and MasterCard Contactless transactions. The applications were extensively tested by Littlepay, the entity responsible for certification, using a testing tool capable of contactless bank emulation cards, and various similar scenarios and error situations in order to test robustness and the requirements of the EMVL3 application. Visa PayWave and MasterCard certifications certify contactless and guarantee the security of using the application's application to process transactions with contactless debit or credit cards at validators/transit terminals.

1.1 Motivation

In Portugal the transport sector is still using outdated technology and is not following the fast improvement on the area. Contrasting, in other countries innovation and adaption to new technologies are a reality already, so, it is mandatory to update the used technologies to enhance not only the travel experience but also to make it a more economic system to the companies because there won't be needed so many workers in contact with the travellers, for instance for selling tickets or checking the ticket vending machines, and there won't be also so many accountability mistakes and all the numbers will be checked much faster.

Besides the convenience to the passengers, better and seamless journeys also reduce the public transport operators pains. Moreover, gradually shifting the process of maintain-

ing a proprietary card to experts already in-market, i.e., the financial institutions, allows the transport agencies to turn their attention to the focus of their business, like the multi-modal mass transit and fare calculation.

Furthermore, the integration of a contactless open-loop solution in public transport current ticketing system facilitates the progress of passengers to this new approach of account-based ticketing, that in the long term reflects into several benefits to the transport operators, passengers and bank institutions.

Costs reduction are one of the many advantages in the agenda for improving public transports ticketing system, including operational and transaction processing expenses. Besides, passengers may foresee higher convenience by using a multi-purpose bank card, and possible offers from their banks and transportation mean. Additionally, banks don't fall far behind, as various benefits came from the development of open-loop payment systems in the transportation industry, for example, gaining from the co-branding and data sharing, thus collecting extra data about their clients which empowers analytical and special offers to retain customers. Finally, although indirectly, environmental gains also exist, like the reduction of carbon emissions, traffic congestion and noise pollution, anticipated as well a diminish in paper waste and plastic use.

1.2 Host Organisation

Focused on providing software components and expert services for integrated mobility solutions and city services is the Card4B Systems (Card4B) mission. The company's nucleus provides services to the transportation industry, including public transport, on-street & off-street parking, tolls, taxis, car-sharing, bike-sharing, on-demand transport, and also to schools, libraries, pools, stadiums, museums, amongst others.

Homogeneously, the organisation members developed projects and new concepts for interoperable contactless ticketing, and also passenger information, embedded systems and smartphones, systems integration and business intelligence.

Mainly, solutions based on ticketing kernel concept, enable communication between all types of terminals and customers' media. So, reinforcing the importance of applying the best expertise and experience to develop modular software solutions adapted to the market.

Card4B Systems not only develops solutions to support customers' activities but also invest in research & development projects, whether at national or international levels. This ethic offers Card4B Systems opportunities to satisfy its customers and to innovate for future solutions.

1.3 Objectives

The project aims to develop an AFC system, particularly an interoperable module to integrate within a ticketing application that constitutes validators/terminals in public transport. Thus, interoperability is a crucial requirement to implement the software middleware independent of any existing hardware, to utilise the current validators in the sector.

Moreover, the validators until now operated with stored-value cards, thus the main project goal is to integrate an account-based ticketing model allowing open-loop bank payments, particularly a contactless and post-paid solution. Hence, the aim of the project must include and securely support EMV transactions. Since EMV has its protocols, each layer composing an EMV level need to acquire a certification in the production environment.

Therefore, the project's significant objectives are as mentioned below:

- Implement an EMV Level 3 (EMVL3) layer capable of submitting transactions to an Automated Fare Collection (AFC) system.
- Implement an EMV Level 2 (EMVL2) layer to perform card data reading to supply data to the layer mentioned above.
- Develop a mock-up component, i.e., a back-office responsible for performing fare calculation and produce charge requests to financial institutions, with the use of an API.
- Integrate the interoperable middleware into an existing ticketing application.
- Study the possibility of certification of the EMVL3 layer.
- Study the possibility of certification of the EMVL2 layer.
- Adapt the layer to EMVL3 certification requirements.
- Adapt the layer to EMVL2 certification requirements.

To note that the adaptation of the system's layers might take longer than the pre-established delivery date, considering that this project is firstly to be employed in a pilot study and then readjusted to future clients.

1.4 Document Structure

Essentially, this report divides the project into six main parts. Firstly, it presents an introduction context of the problem and the solution, i.e., the project's scope. It also, confers a background with the contemporary state of the art and presents related work around the world. Thirdly, this report provides an explanation of the project's core, and an analysis

of the use cases and requirements, later on it illustrates and describes the architecture design, based on the previous analyse. Then, the development process is carefully clarified. Subsequently, the report details the mandatory certifications for deploying the ultimate solution in a live environment, as well as the acquired EMV Level 3 Certification, and the testing methodology. Lastly, it elaborates a discussion on the main conclusions and future work.

The report has the following structure:

- *Chapter 1* – The first chapter provides an overview of the project's scope and its context, as well as the motivation that drove this project. Card4B Systems as the host organisation is also introduced. In the end of the chapter, the report clearly specifies the main objectives of the project, and also of this work.
- *Chapter 2* - Modern state of the art in terms of mobility-as-a-service, ticketing, contactless payments are present in this chapter. Finally, the chapter contains worldwide related work within the scope of the project, as well as a brief discussion on the ticketing solutions presented in the chapter.
- *Chapter 3* – This chapter contextualises the reader about the project, and also, it presents the stakeholders involved. To design a solution architecture, the chapter explains the analysis process first, in particular, the use cases and requirements. Following is the architecture design, plus control and data flow of the developed solution.
- *Chapter 4* – The fourth chapter provides a description of the implementation phase, by dividing and detailing the transaction processing into minor sections. In the end, this chapter explains the integration of the developed solution in an existing ticketing application.
- *Chapter 5* – The project's evaluation is provided in the fifth chapter. Particularly, the solution required certifications for a production environment, and the testing methodology used and its results. Subsequently, the chapter provides an overview of the EMV Certifications, as well as detailing the obtained EMV Level 3 (EMVL3) Certification.
- *Chapter 6* - The last chapter, summarises the project's scope and results, and then provides a discussion that analyses in retrospective the planned and achieved tasks, results are also a target of this discussion. Lastly, a clarification of the required future work and improvements of the project.

Chapter 2

State of the Art

This chapter intends to contextualise the reader before further project specifications. In doing so, it enunciates the contemporary state of the art in sections, by linking the new era of Mobility-as-a-Service (MaaS) with the existing ticketing problems and contactless payment solutions. Hence, describing the current *modus operandi* and introducing new solutions.

2.1 Mobility-as-a-Service

In 2018, the World Intellectual Property Organization (WIPO) registered on average 9 thousand patents per day that reached over 3.3 million Intellectual Properties (IP) for the entire year [7], which reveals the global modernisation adjacent to innovations. Nevertheless, transportation is still considerably underdeveloped in the adoption of technologies to reach its full potential.

Furthermore, the accelerated growth of the human population and the continued global trend of hyper urbanisation increases the demand for transportation, which raises issues for the future — namely, CO₂ emissions, noise, congestion, climate changes, demographics and socio-economic alterations [1, 8].

Therefore, it is crucial to enhance the conditions to achieve sustainable mobility, e.g., developing vehicle technology and Information Technology (IT) infrastructures. Also, changes in people's behaviour are expected to reduce private car dependency and the shared trips with fossil-fuelled vehicles [1]. One strategy involves making structural changes to the transport framework in order to expand the availability and quality of alternative transport options, for example, Karlsson et al. proposed the introduction of car-sharing schemes and multi-modal solutions [1].

2.1.1 The Concept

In the later years, a new mobility concept raised, designated as Mobility-as-a-Service (MaaS). Although still ambiguous, the concept of MaaS aims to promote the use of multi-

modal transportation services, from the public and private sectors [9]. Mobility-as-a-Service also envisions the integration of the currently fragmented tools and services that a passenger requires to conduct a trip on a single digital platform. Consequently, MaaS travellers could access to simple, flexible, reliable, price-worthy and seamless travel in city and intercity trips [8].

In conclusion, as stated by MaaS-Alliance the aim of Mobility-as-a-Service must be the best offer for its clients, that is progressively sustainable, less expensive and as helpful as a private vehicle [10]. Figure 2.1 depicts the present circumstances vs. the MaaS model when in theory.

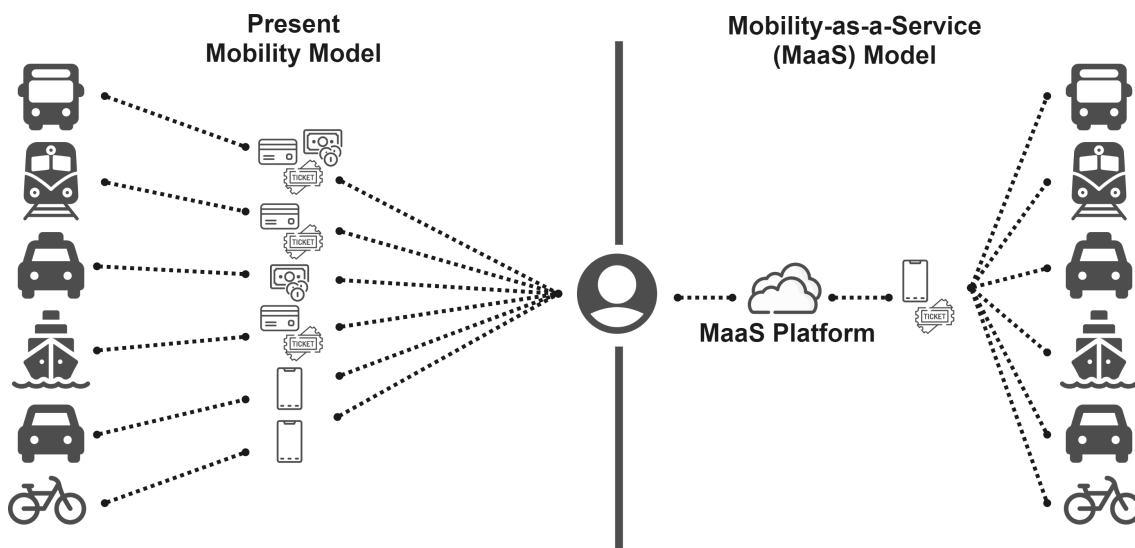


Figure 2.1: Comparison between the Mobility-as-a-Service model and the present mobility model

2.1.2 Core Characteristics

“Mobility as a Service is a user-centric, intelligent mobility distribution model in which all mobility service providers’ offerings are aggregated by a sole mobility provider, the MaaS provider, and supplied to users through a single digital platform.” Furthermore, “MaaS is a subscription service that could provide either pay-as-you-go options or subscription packages that include various combinations and amounts of transport modes.”

— Kamargianni and Matyas [8]

The above definition summarises the new transport solution and enables the interpretation of the core characteristics. The perception of each characteristic and interpretation as part of a whole allows a better understanding of the business ecosystem proposed by Kamargianni and Matyas [8]. Accordingly, Jittrapirom et al. literature review and further

research [9], concluded that when implementing a MaaS the following characteristics should be considered:

- **Integration of Transport Modes** – As already mentioned, the focus of MaaS is to enable and encourage the use of various transport services to guarantee to its users seamless door-to-door inter-modal and multi-modal journeys. Users can choose any means of transport from public transports to taxis, car-sharing, ride-sharing, bike-sharing, car-rental, or even on-demand services, among others available. Also, long-distance buses, trains, flights and ferries can be elected to break the boundaries of an urban city.
- **Tariff Option** – Mobility packages and pay-as-you-go are the types of tariffs that users can access within MaaS platform. The packages should include a certain amount of kms/minutes/points for the various transport modes and the possibility to deduct and/or exchange them to monthly payments. The pay-as-you-go option prices passengers according to their practical usage of the service, thus, offering advantages even for occasional trips.
- **One Platform** – Hietanen describes MaaS as a mobility distribution model where the customer's primary transportation needs are fulfilled over one interface [11]. Moreover, Kamargianni and Matyas recognise the need for an intelligent and digital platform to be supplied to users [8], reinforcing the importance of Information and Communications Technology (ICT) and IT infrastructures for the correct operation of the MaaS system. The MaaS digital platform, which can be either a mobile app or a web page, offers an all in one solution of the available services and transportation, through which the end-users access the required services for their trips. For instance, trip planning, booking, access to real-time information, ticketing, payment, and other useful services, such as weather forecasting, synchronisation with own activity planner, travel history report, invoicing and feedback.
- **Multiple Actors** – Kamargianni and Matyas proposed the perception of MaaS as an ecosystem, with actors that have different and vital responsibilities to the correct operation of the system [8]. These actors interact with each other through the digital platform. Actors are classified based on their relationship with the MaaS provider. The following are the major actors within the ecosystem (see more in [8]): 1) Transport operators, 2) Data providers, 3) Technical back-end and IT providers, 4) ICT infrastructure, 5) Ticketing, and payment solutions providers, 6) Investors, 7) Insurance companies, 8) Regulatory organisations, 9) Universities and research institutions, 10) Customers. Other actors can also cooperate in the ecosystem, for instance, local authorities, telecommunication, and other relevant companies.

- **Use of Technologies** – The new emerging technologies when combined, are capable of revolutionising the individual and joint mobility. Markedly, automated vehicles, peer-to-peer sharing applications, the Internet of Things (IoT), devices, such as mobile computers or smartphones, GPS, and a reliable mobile internet network (Wi-Fi, 3G, 4G, 5G, LTE). Additionally, e-ticketing and e-payment systems, database management systems and integrated infrastructures of technologies are also necessary. Thus, the ICT progressively fosters the rise of new business concepts, that are essential to implement MaaS in practice, for example, to optimise the transport network, or to promote better utilisation of infrastructure and seamless trips.
- **Demand Orientation** – As previously defined, MaaS is a user-centred paradigm, consequently, seeking a transport solution that best fits the customers' expectations via multi-modal trip planning features and responsive on-demand services.
- **Registration Requirement** – Following the user-centric approach and ensuring the end-users' requirements satisfaction in an effective and efficient way, subscriptions expedite the convenience of the services along with the service personalisation. Therefore, registration is mandatory to succeed in the previous aspects.
- **Personalisation** – Considering each end-user is unique and have his/her own requirements, the system is capable of providing specific recommendations and tailor-made solutions based on the customer's profile, as well as the user's preferences and travel history among others.
- **Customisation** – The customers' satisfaction and loyalty increases when they can modify the options according with their preferences. So, it's mandatory to grant the users the possibility to adjust basic aspects to their choices.

2.1.3 Business Ecosystem

The ecosystems observed in nature can be perceived as an example and a similar strategy can be used for organisations, namely, as presented by Moore this extend vision allows to perceive "a company not as a member of a single industry but as part of a business ecosystem that crosses a variety of industries" [12]. Therefore, companies evolve throughout innovations, as they work cooperatively and competitively to establish new products that satisfy the customer's needs.

For instance, Apple Inc. is a leader of an ecosystem that converges with four significant industries - personal computers, consumer electronics, information, and communications. Apple's ecosystem incorporates an extensive network of suppliers, distributors, competitors, government agencies, and a vast number of customers in the various market segments, and so on. Leadership empowers all members inside the ecosystem to invest in a shared future where they anticipate profiting together [12].

To sum up, all elements in the ecosystem influence and are influenced by others, creating a continually evolving relationship. For that reason, entities shall be flexible and capable of adapting to persist. Since the MaaS model has a complex value proposition, difficulties arise when structuring the system network.

Kamargianni and Matyas classified the ecosystem in three layers, each with distinct actors and roles [8], depicted in Figure 2.2. A layer represents the level of involvement with the MaaS provider. The first layer is denominated the core business and consists of the MaaS provider, data providers, transport operators, and customers/users. Then, there's the extended enterprise in the system. It includes technical back-end providers (IT infrastructure), ticketing solutions, payment solutions, dynamic multi-service journey planners, ICT infrastructure, and insurance companies. In the last layer, the business ecosystem involves investors, research institutes, universities, media & marketing firms, unions, and regulators & policy makers. Some authors discuss the correct location of the regulators & policy makers in the layered ecosystem, particularly proposing their location to be in the core business.

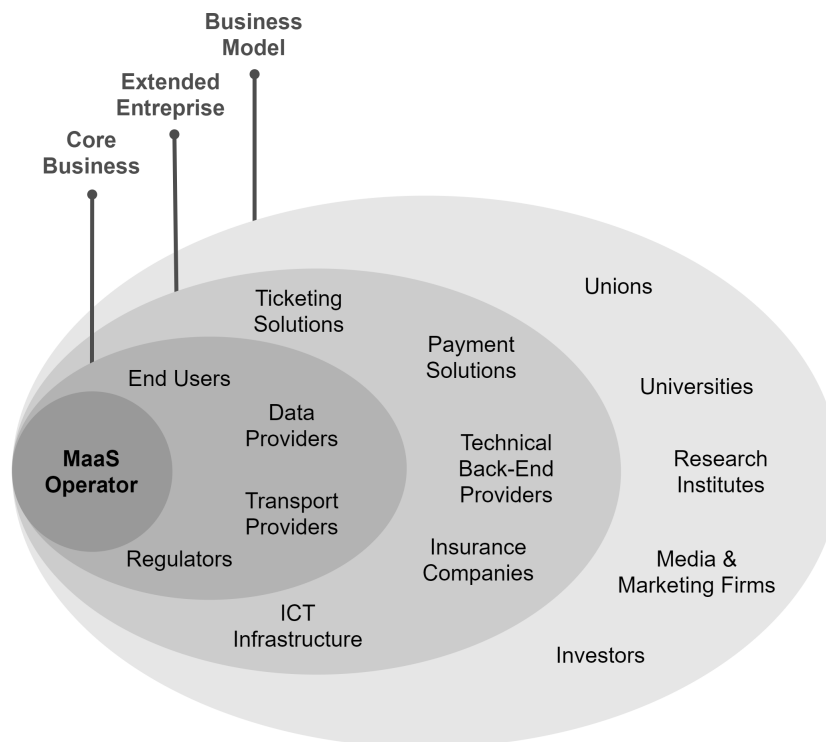


Figure 2.2: The Mobility-as-a-Service business ecosystem

2.1.4 Levels of Integration

Nowadays, numerous initiatives marked as MaaS merely provide travel data and no alternative to booking or paying for tickets [13]. Most of these initiatives have different levels of integration. The main differences are related to ticketing, payment, mobility packages,

information, services, and policies, as reported by Durand et al. [13].

Sochor et al. proposed four levels of integration [14], represented in Table 2.1, based on [13]. The first level is about information, usually aggregates projects that include multi-modal travel planners, price information, and other relevant real-time data, such as transport occupation, delays, cancellations, among others. In second is booking & payments integration, which incorporates initiatives that have means to find, book and pay for a single trip. The third level groups schemes that offer services, for instance, subscriptions and contracts. Finally, the fourth level combines initiatives that integrate societal goals, i.e., the integration of broader purposes, like socio-economical, as well as environmental policies or initiatives, and so forth.

It is essential to mention that the various levels don't depend on each other. Furthermore, they may only fill an integration level partially. Consequently, an initiative can be in level 3 without entirely reach level 1, or solely partial implement level 2, for example.

Table 2.1: Levels of mobility integration in Mobility-as-a-Service

Level	Type of Mobility Integration	Projects
4	Integration of societal goals Regulations, policies, incentives, etc.	-
3	Integration of the service offer Subscriptions, contracts, etc.	Whim, UbiGo
2	Integration of booking & payments Single trip, find, book, pay (pay-as-you-go)	Smile. MyCicero, Hannovermobil
1	Integration of information Multi-modal travel planner, real-time information, etc.	Google, Transport for London
0	No integration	Hertz, Sunfleet

2.2 Ticketing

Societies mainly rely on economic and social aspects, moreover the mobility of passengers and goods. In recent years, modern economies proved to have a significant increase in demand for transportation and accessibility [4], which raises socio-economic and environmental issues. Thus, sustainable transportation is the primary driver for developing public transport, according to Zalar et al. in [4]. Furthermore, in the digital generation and cashless economy, public transportation must keep pace with technology improvement to meet societal expectations.

Ridership is amongst the critical performance indicators of sustainability regarding economic, social, and environmental factors of public transport [4]. Improving the ticketing system is an example of the methods that public transport operators require to attract

more passengers and retain existing travellers to use public transport. Other qualitative factors, like, travel time, fare price, and travel convenience, are also reviewed and considered with plenty of attention by transit operators. For instance, Zalar et al. developed a methodological framework for measuring the level of convenience of transport ticketing systems [4]. Later, a survey employed the developed method. The results concluded that contactless payment cards ticketing systems offer higher convenience, a better and more seamless travel experience than traditional smart systems.

2.2.1 Major Problems

The majority of countries around the globe provide reasonably satisfying transport services, although common problems exist, mostly caused by the non-availability of alternative modes, lacking transportation, and inefficient ticketing and payment systems. According to Kazi et al., several passengers regularly face the following challenges [3]:

- *Additional waiting time at bus stops* – Often, passengers have to wait an unnecessary and unknown amount of time for transportation, which causes considerable dissatisfaction to the travellers. Besides, more time commuters await higher is the number of passengers that crowd the transports.
- *Inadequate time for getting tickets* – When the affluence of commuter traffic is more significant, it's difficult and time costly to get a ticket, not only to purchase a single ticket in a crowded bus, and also to top-up a traditional smart card on ticket vending machines.
- *Non-refund of balance* – Commonly buses or ticket vending machines have no change, which adverse the travellers to pay with cash for their tickets.
- *Negligence to grant seats to other passengers* – Frequently, passengers have to stand all the time of their trip since there is no algorithm for seat allocation. A few commuters remain on their feet all the voyage while some sit when they board the transport subject to the available seats.
- *Excessive misuse of paper* – Excluding the commuters who own passes, all other passengers take tickets. Thus, the volume of paper demanded to print transportation tickets is considerably high, which prompts excessive paper waste.
- *Usage of cash* – In a cashless economy vision, money transactions don't employ cash, so passengers that acquire tickets handling cash contradict the system. For instance, most buses only accept cash and hardly have money change to purchase single tickets.

2.2.2 Electronic Ticketing Systems

Paper has numerous applications, moreover, paper tickets, which date back to 1920 [15]. Its continued usage and waste cause various problems to the environment, therefore a new solution to substitute it was mandatory. With the evolution of machinery and society, electronic ticketing solutions arose.

As stated by Nipa et al., electronic ticketing, or e-ticketing, is a paperless ticketing solution where information can be stored and read through the usage of electronic devices [16]. In 1994, United Airlines was the first airline to successfully adopt e-ticketing [15]. Freedom from carrying paper and documents and the security of the information were the foremost motives that prompted the use of e-ticketing by the airline companies and the travellers. Furthermore, firms realised the extra gains, like stop paper-ticket fraud, eliminate lost/stolen tickets and substantially decrease document process and distribution costs; paper tickets cost as much as \$10 to process, while an e-ticket just \$1 [16, 15]. Different sectors followed the airlines' example, such as transportation, health, and logistics.

The world is getting highly dependent on the internet. Consequently, several countries are now using internet-based e-tickets in distinct sectors [16]. So, the enhancement of technology facilitates sectors like transportation to shift to digitalization. Thus, implementing an automated system that uses e-ticketing is beneficial to this digitalization process [16].

Nowadays, efficient and interoperable fare collection has higher importance than has ever had in the past. When adopted, multiple payment options have the potential to decrease operating costs and enhance public transport convenience by solving many of the problems mentioned in section 2.2.1. The available payment options a mass transit authority offers can positively influence customers to embrace public transport services, which may cause sustainability and economic growth to benefit from it indirectly.

Moreover, the volume of data that can be stored differs from the selected type of e-ticketing [16]. Presently, several Automatic Identification and Data Capture (AICD) methods exist, i.e., technologies employed to collect data with different digital mechanisms, namely, Bar Codes and Optical Character Recognition (OCR), Magnetic Stripes, Radio-Frequency Identification (RFID), Smart Card, Voice Recognition and Near Field Communication (NFC). Additionally, working with Geographic Information System (GIS) technology enables e-ticketing to provide tracking techniques.

E-Ticket

An electronic ticket, abbreviated e-ticket, is a digital form of a paper ticket as it represents a contract between the owner of the ticketing and the service provider, with the advantages of offering passengers: security, flexibility, cost, and convenience [3, 17]. Similar to the traditional paper ticket, e-ticket can store the standard assurances, too, as seating allocation or other flexibilities.

The risk associated with stolen or lost tickets is lower for passengers since an electronic format secures the e-ticket. Furthermore, customers may book electronic tickets and purchase them online, without the intervention of service personnel, and there are also simple payment methods available, for example, with the use of a digital wallet, instead of handling cash [3]. Lastly, e-ticket helps to reduce the carbon footprint and the waste of paper, forwarding to a sustainable future.

2.2.3 Automated Fare Collection

Automated Fare Collection (AFC) system automates ticketing systems, including the transportation's network. Generally, AFC systems provide integrated ticketing solutions, which can be defined as the acquisition of single tickets for multi-modal transport, i.e., “combining all transport methods in one single ticket” — thus fostering a more sustainable multi-modal transport and attractive for passengers by promoting the more efficient use of the existing infrastructure and services [18]. Eventually, it might provide better air quality, less congestion, higher efficiency of the transport system, capacity increase, social inclusiveness, boosting jobs and innovations.

The development of an integrated ticketing system requires an active integration in the several stages of the travel chain, for instance, when passengers search for information, book, or pay, and also for revenue sharing between the different actors, as well as ticket issuance and validation, amongst others. Accordingly, an AFC is intrinsically coupled with interoperability based on universal standards.

An AFC system commonly enables transparency and efficiency to transactions, and so it can enhance the convenience to travel within a city. It might also expand the number of passengers using transport systems, as well as retain the existing ones as end-users naturally shift towards solutions that make their lives simpler. Therefore, a great AFC system can make a city a better place to live in.

Multiple components incorporate an AFC, including fare media, devices to read/write, station computers, back-office systems and central management system. Although passengers interact the most with devices to read/write media using their fare media, which have been in recent years a stored-value card.

To reduce the end-users pain of caring paper tickets and the outdated validation it was required, the transportation sector introduced contactless smart cards [18], however with the evolution of technology better and more convenient fare media are available as the use of contactless bank cards or virtual cards hosted on mobile phones. Through the usage of the existing media that passengers already own and hold, all actors involved can benefit.

2.2.4 Closed-Loop Payment Systems

Closed-loop payments refer to proprietary payment cards with a single-purpose, for illustration, a store credit card, a gift card or even a wristband. The primary purpose of these proprietary cards is to transact at a particular store or group of stores owned by a business. Moreover, customers can top-up stored value cards for continued use.

Proprietary cards are frequent in the transport industry, principally due to the advantages they have to transit operators, such as ease of use and internal payments processing, thus reducing the cost of operations, and enabling the agencies to monopolise the payment instrument. However, circumstances are shifting, and users demand higher speed, mobility, cashless, and social networking with their peers [19]. Transportation agencies soon have to consider the integration of different service providers and invest in technology to meet the customers' expectations, given that closed-loop payment systems cannot directly fulfil.

The majority of transport operators already engaged in tremendous investments to implement new technologies to replace cash, tokens, swipe cards, nevertheless, most of them only have a single purpose, i.e., to be used for transportation agencies. So, despite the expenses, the agencies merely replaced cash for a proprietary card, with limited uses, hence, not developing the ecosystem to benefit from other services. Zamer mentioned that public transport operators could offer services such as loyalty points, transaction interchange, agile service deployments, productizing their services, or also understand the users consuming behaviours after all these features are crucial to promote smart city strategies and to reduce urban planning difficulties [19].

Contrasting the banking industry, who already possesses the know-how involved with card life cycle and transaction processing, transit authorities that implement proprietary card programs have higher expenses and perform complex procedures to achieve the equivalent set of processes, and still cannot accomplish the economic scale and customers offers of bank institutions.

Following are significant challenges that transit authorities may face in the future if they continue to pursue closed-loop payments:

- *Resources and operational overheads* – the rate of emerging innovations is high, therefore soon terminals and fare gates become obsolete, and the cost associated with maintaining such devices increases by time. Consequently, translating in unnecessary operational overheads to sustain a satisfactory level of customer fulfilment since the customers' expectations shift with the technology evolution, and these devices won't correspond to it.
- *Passengers inconvenience* – the passengers must purchase and carry payment instruments with the single purpose to use it in transportation, instead of directly using the ones in their wallets, like debit/credit cards, or prepaid cards that have far

more applications.

- *Lost revenues opportunities* – the agencies miss revenue opportunities, such as revenue sharing from co-branded interchanges or usage fees, and have to invest by themselves in direct marketing, resources, and technology, to have vendor control, which can potentially diminish competitiveness.

Transport agencies spend millions a year to maintain stored-value card system, and this amount of money can be invested in major profitable business plans by simply offloading the payment collection to open payment system rather than the traditional self-contained closed system.

2.2.5 Open-Loop Payment Systems

Opposite to closed-loop payments, open-loop links the consumer's credit card, debit card, gift card, or prepaid card directly to the point of sale device to acquire goods or services [19]. To notice some limitations like the customer is subject to the terms and conditions of the card issuer and utilised at merchants that accept the card's schemes, being Visa and MasterCard the most common.

Considering the infrastructure is already built, and in the market for numerous years, credit and debit cards are widely handled and accepted. For that reason, transit authorities could profit from the most meaningful advantage of open-loop cards by utilising previously established and trusted networks in their fare collection payments, rather than supporting their payment systems to process and settle payments themselves [19]. Thereby, as mention previously, transit agencies suffer from several overhead costs.

Visa and MasterCard affiliated to the bankcard standards since long ago; conventional financial systems are responsible for setting these standards. Member banks also adopted these norms, making them the appropriate intermediary to process high volume transactions by applying the established settlement, reconciliation, and dispute management processes.

Next, are the pros and cons of open-loop cards for each party, namely the transport operators, the passengers, and lastly, the banks. Table 2.2 presents a collected version of those.

Transport Operators

Although the bankcard standards have a cost of processing and interchange fees associated for the transportation agencies, they still enable cost reduction, relatively to operating closed-loop payments, i.e., primarily the acceptance, card life cycle, and financial settlements, among others [19]. A decrease in costs concerning the maintenance of an extensive infrastructure operation in issuing and managing a closed-loop payment scheme is experienced by the transport operators too.

Table 2.2: The pros and cons of open-loop payments for the major parties involved

Actors	Advantages	Disadvantages
Transit Operators	<ul style="list-style-type: none"> - Reduction of operation, and transaction processing costs; - Decrease in the number of interaction points; - Benefits from co-branding, and data-sharing; - Enable convenient user experience to customers, by providing a familiar experience. 	<ul style="list-style-type: none"> - Implementation of additional security, and data protection; - Funds transference from 3rd parties takes longer; - Potential issues related with transactions dispute; - Possible loss of revenue when transactions are not correctly captured.
Passengers	<ul style="list-style-type: none"> - Higher level of convenience by using their multi-purpose bank cards; - Likely to receive better offers from their banks, based on geolocation and data analytics. 	<ul style="list-style-type: none"> - Use of vulnerable payment technologies; - Vulnerable to phishing attacks.
Banks	<ul style="list-style-type: none"> - Benefits from co-branding, and data-sharing; - Additional data collected about their clients; - Possibility of offering discounts and special promotions based on costumers spending behaviours and geolocation patterns. 	<ul style="list-style-type: none"> - Specification and support for new standards, and guidelines for open-loop transit systems; - Implementation of additional security, and data protection.
Others	<ul style="list-style-type: none"> - Indirectly decrease on carbon emissions, and noise pollution due to the reduction of traffic congestion; - Diminished plastic use in the production of proprietary cards; - Minimise paper wastage. 	N/A

Furthermore, an open-loop program reduces costs with transaction processing, as transactions are aggregated and processed in bulk, and sent to the acquiring partners [19]. In the future, several benefits might emerge as a consequence of co-branding and data sharing with banks. For example, the data collected by both partners can be the target of an analysis to offer specific promotions to passengers according to their spending and travel behaviours.

Open-loop payments diminish the number of interaction points between passengers and the transportation fare collection system [19]. Consequently, facilitating more natural user experience and so satisfying the customers' expectation of a smooth, simple, and seamless travel, which is one of the main goals of transport operators. Not to mention, the convenient use of debit, credit, and prepaid cards already exist in the customers' wallets, reflecting positively on the passengers' trip.

Regardless of the various benefits open-loop payments offer, there are challenges to overcome, mainly related to transaction security and data protection [19]. In particular,

transport authorities require extra attention when securing the payment transaction, as well, during the communication between the card and the gate barrier or the point-of-sale device, and the transaction processing in the acquiring bank. Zamer proposes mitigating these obstacles by working with trusted service providers, and by conducting annual audit inspections to decrease the likelihood of being exposed [19]. Another crucial aspect is protecting and properly archive the transactions performed, following all norms and guidelines; moreover, the current established General Data Protection Regulation (GDPR). To summarise, it is highly advised to foster data protection and security policies to eliminate the exposure.

Additionally, possible revenue loss exists due to transaction matters, in case of transactions not being captured correctly. The existing models typically store the balance on the card, and financial transactions are calculated immediately, therefore, decreasing the expense of processing and reduce the margin of errors.

Passengers

Likewise passengers gain from open-loop payments too, specifically regarding the level of convenience, as they don't have to agonise about having a special card with a single purpose [19], alongside the many other cards that consumers carry in their wallets. Another advantage is potential promotions and tailor-made offers they can receive from their banks, based on geolocation.

However, passengers are vulnerable to phishing attacks [19], a consequence of the use of easy-exposed payment technologies. Therefore, customers rely on the transport authorities and bank institutions to protect and secure their private data and interests.

Bank

The potential of the data collected from the transportation industry presents the banks a new source of profit. The co-branding program with the transportation agencies grant the financial institutions to comprehend where the customers are using their cards [19]; this promotes discount offerings and awarding their clients with special promotions, based on locations and usages [19]. Acknowledging banks pair with transit agencies, they also need to ensure data security and protection, as well as secure transactions.

Others

An experience like the open-loop payments provides not only benefits to all the involved parties but also helps, directly and indirectly, the environment and the society [19]. As the open-loop system employs e-tickets, therefore paper waste is reduced, and so the carbon emission, this last one is also supported if the level of convenience is such that more commuters select public transport instead of driving their cars. And so, traffic congestion and

noise pollution diminish. To conclude, the society and the environment might indirectly value from a shift to this approach. Although utopic, it promotes smart city initiatives.

As a result of the benefits mentioned earlier, and mainly due to the improved user experience, several transport authorities genuinely aim to adopt the open-loop payment system. By adopting the open bankcards, transit operators agree with the bankcard standards. And in the long term, transportation operators might profit from the co-branding and data sharing with banks, and further, be ready to negotiate a competitive deal for merchant management and prepaid programs. Consequently, the transport agencies shift their concerns from the banking market to focus on the core of the operations of mass transportation and transit management, furthermore enhancing the passengers' experience.

2.2.6 Account Based Ticketing

Account-based ticketing systems concern the need for identifying customers using accounts. Thus, rather than a ticket, a stored-value card or a virtual smart card hosted on a smartphone, travellers have an account in the back-office [6], to benefit from the service's convenience the payment occurs during or after the trip ends.

Since the account-based ticketing architecture relies on a back-office, this is the primary source of trust in the system. The back-office is responsible for applying crucial business rules, perform fare calculation, and transaction settlement [20]. Moreover, the back-office manages which passengers can travel by validating the traveller's ticket or token and confirm the customer's right to travel, and this is where the account is required. Contrasting the card-based architecture, where the fare payment media and card reader decide upon approve or deny the fare payment transaction, as well as perform fare calculation [20].

Furthermore, the validation process is reported by Smart Card Alliance as follows. The terminal reads the information stored on the fare payment mechanism and transmits it over a network to the back-office. Then, the back-office verifies the card and returns a signal of approval or denial, which enables the terminal to open the gate or to signal the rider and the transit operator on whether to allow passage [20].

Benefits

Implementing an account-based ticketing solution has various advantages to the transport agencies summarised following.

- *Proprietary cards cost reduction* – transit operators by adopting account-based ticketing systems discharge themselves from issuing, managing, and maintain a proprietary stored-value card, which signifies a decrease in expenses; this is mainly due

to bank cards become the issuers of such cards; the cost of cash management also diminishes [19].

- *Basic smart card profiles* – passengers carry an identifier at ticketing gates, fare boxes, validators or fare media only read, as the back-office performs the processing; therefore, these types of equipment don't require the same level of intelligence and complexity they did before, presenting potential and vital cost savings [6].
- *Flexible and streamlined operations* – transport agencies by using account-based ticketing system with a standard payment instrument enable a more streamlined and flexible business model [19]; this allows the operators to provide variable pricing models, and so, promoting and increasing usage, as well as delivering smoother and higher quality service [6].
- *Enhanced agility* – updates to passenger ticketing don't demand re-issuance of a ticket, as the ticketing process is centralised at the back-office, consequently promoting greater agility [6].
- *Managed risks* – limits can be set instantly on a passenger's account at the back-office to manage fraud; in case of connectivity issues, agencies control the entrances of passengers based on the risk status registers present on the card, therefore allowing the account-based ticketing flexibility by managing operator losses and traveller frustrations during connectivity down-time [6].
- *Loss of cards doesn't imply loss of funds* – when a traveller loses their card, they are not required to contact and request a new card from the transport operators; they must contact their bank and follow the already defined protocols [19]; loss of funds doesn't occur considering no data concerning the fare balance is present on the card [6].
- *Passenger convenience and choice* – consumers are increasingly adopting mobile and contactless device usage in other industries, and demand that experience in other sectors like the transit [6]. Account-based ticketing allows passengers to decide how they wish to identify themselves; amongst the options are smart cards, mobile devices, or wearables [6, 19]; furthermore, passengers with pre-funded accounts don't have to bother about the balance for their next trip [6].

Challenges

Although the benefits of account-based ticketing appear explicit, several technical complexities in implementing such solutions arise, particularly issues related to ensuring effectiveness, security, and reliability. The challenges to overcome when developing an account-based system are further on.

- *Security* – one of the main requirements of account-based ticketing is strong authentication, to reduce the chance of security issues or card corruption; thus, the industry should adopt standard cryptography. Minimised writes in the card fosters card reader performance, which is a significant gain to the system; this can occur since the card doesn't store the fare value [6].
- *Offline risk management* – account-based ticketing by relying merely on an online connection has problems that might interrupt a business flow when the connectivity is down [6]. A status register may be necessary, to indicate funds or lack of them, or even denial due to previous behaviour, thus higher risk; a solution like this offers a better level of risk management. See [6] to understand better customer convenience registers.
- *Speed* – to provide contactless travelling while being seamless and convenient, implementations shouldn't need longer than 350ms from a tap to an approval signal. So, meeting the international transaction time standard, which might be challenging to achieve when the system relies on online connectivity and is experiencing an offline period [6].
- *Upgrading proprietary systems* – transport operators invested numerous on developing their systems; consequently, the integration of account-based ticketing may be costly and complex to adapt to the existing systems, and an implementation that follows open standards and employs current systems might be safer and profitable [6].
- *Inclusivity* – account-based ticketing solutions should be able to include those without a bank account, therefore ensuring all users still perform their journeys safely, securely, and conveniently; a potential solution is pre-fund accounts [6].

Thoughtful transit operators need to reconsider their fare collection strategies and invest in new payment methods to ensure their success in the future. So, the first step would be to shift to account-based ticketing with open-loop payment systems, the possibility of prepaid cards and contactless payments to enhance the travel experience should be added. The involvement of prepaid cards or pre-fund accounts in the ticketing system is vital for passengers that don't have a bank account [19, 6]. Mainly, consumers employ prepaid cards on low-value payments and to travel on the transit system [19].

2.3 Contactless Payments

The banks revolutionised the industry in 2007 with the introduction of contactless payments. Until that moment, payments only employed contact methods, like magnetic

stripe, and later chip-and-PIN cards. It was precisely in 2007 that the first contactless card transaction occurred, to be specific in the United Kingdom. Since then, the contactless payment industry has highly expanded and quickly incorporated thousands of banks, credit card companies, merchants, and retailers around the world.

Contactless payments are primarily payment transactions involving no physical contact between the customer payment device and the point-of-sale (POS) terminal. This modern and secure method enables consumers to purchase goods or services by tapping nearby (less than 5-10 cm) their contactless debit or credit card, wearable, or Near Field Communication (NFC)-enabled smartphones at participating merchants [21]. For that reason, the payment account information, and other relevant data, are communicated wirelessly, mainly via Radio Frequency (RF).

The term contactless refers to the accomplishment of the exchanging of signals and the transfer of power to the consumer's device without the use of galvanic elements, i.e., the lack of a direct line from the external interface to the integrated circuit(s) found in the card. A smart card is a device with credit card dimensions which uses a small microchip to store and process data, and employ either Radio-Frequency Identification (RFID) or Near Field Communication (NFC) technology to communicate. Smart cards have replaced old magnetic cards in many cases as they can handle more details and offer more flexibility. Smart cards are now in use in various industries, including retail, transit and security.

Researches demonstrates that the use of contactless payments benefits customers, issuers and merchants [21]. Consumers enjoy enhanced convenience, speed and user-friendliness while issuers and retailers take advantage of quicker transaction times, higher transaction volume, lower operating costs and penetration into the cash payment market.

2.3.1 Payment Methods

The way people pay in different regions and circumstances have suffered several improvements from the payments industry over the last few years [22]. At the moment, multiple payment options are available to employ in various businesses. Particular in the transit industry are four the principal methods of payment used [19]. According to The Paypers and despite all the innovation emerging to facilitate digital payments, cash is still leading the selected payment methods at the checkout [22].

Cash

One could question if the economy is moving towards cashless transactions. However, despite the evolution of the technology employed in the payments industry, cash is yet dominant in various regions around the world. The reason for that is mainly socio-economic factors, region development level, and technology adoption.

Credit/Debit Cards

Progressively, consumers have become more comfortable with using their debit, credit and prepaid cards to pay low-value transactions [22], this is one of the most used alternatives to replace cash [19]. Customers pay their online purchases even more with credit cards, being these amongst the most common online payment methods.

The use of credit/debit cards reduces the overhead costs of businesses from handling cash since these transactions typically cost twice as much as non-cash payments in overhead. Another advantage is that this method provides an opportunity to comprehend buying behaviours and spending patterns [19].

Proprietary Cards

Transit agencies, between other firms of distinct industries, developed their proprietary cards. Moreover, transportation operators applied their fare payment system in the proprietary cards [19]. The reason behind such decision lies years ago when the existing payment options were confined, and diverse alternatives weren't available to the customers.

Proprietary cards are still used and rooted in the system, notwithstanding the higher cost of operations, that gradually increase as technology evolves and devices became obsolete and challenging to maintain [19]. Thus, not allowing transit authorities to reduce costs and generate further revenues and invest in new innovative services.

Prepaid Cards

Lately, the adoption of prepaid cards has risen, as a way of avoiding fraudulent online transactions and also due to the emergence of gaming communities. Furthermore, Zamer emphasised the application of prepaid cards in the consumers' everyday life [19]. Since these cards are re-loadable and used by people without a bank account, employers for salary payment, and also from the government for social benefits [19]. Mostly, consumers utilise prepaid cards to handle micro-payments, for instance, to travel on a transit system.

Mobile Payments

Continuously, the e-wallet ecosystem, i.e., electronic wallets, is expanding worldwide, namely AliPay, Apple Pay, Google Pay, Samsung Pay, and others, dominating over half of the global market transaction with mobile payments [22]. Despite the quick adoption of this new trend by customers, little efforts have been performed to include mobile as a payment instrument [19].

Jens Bader, the co-founder of MuchBetter, a mobile payment app, draws attention to the significant role that digital wallets have in the context, highlighting the convenience level that e-wallets provide to the consumers [22]. Notwithstanding the benefits of digital

wallets, the greatest obstacle is trying to fill the technology gap separating the existing fare gates and today's mobiles [19]

2.3.2 The Evolution of the Payment Industry

Payment devices and methods have changed significantly over the past few years. For a long time, purchases handled using physical gold coins, and at the moment, consumers use digital wallets. Presently several firms are providing financial services.

The payment industry has developed into a sophisticated space with the presence of digitalisation. Two types of cards existed before contactless cards, the traditional magnetic stripe cards which were replaced later by chip-and-PIN cards.

Magnetic Stripe Cards

Invented in the late 60s magnetic stripe is amongst the most successful technologies in the history of modern business. Essentially, magnetic stripe cards store data in tracks of magnetic strips fixed to plastic cards, and when a card is swiped at the point-of-sale (POS) terminal, the card's data is read by a magnetic head [23].

Chip-and-PIN Cards

Introduced in France, chip-and-PIN cards contain a data-enabled microchip and require consumers to provide a signature to complete transactions, which presented an enhancement in security when comparing to the magnetic stripe cards, this was mainly due to the encryption and digital technology the microchip provides [24].

Contactless Cards

In contrast, contactless payments only require the consumer to tap the contactless card or device near a POS terminal, that has been previously equipped with contactless payment technology. For this reason, contactless payments are often referred to as "tap-and-go" by some banks and retailers. Considering that contactless payments do not demand a signature or a personal identification number (PIN), transaction sizes on cards are limited, and the allowable amount for contactless transactions varies with country and bank.

EMVCo [25] combines six significant payment organisations, which are American Express, Discover, JCB, MasterCard, UnionPay, and Visa, by managing and evolving the EMV Specifications and associated compliance processes. EMV got its name from the card schemes Europay, MasterCard, and Visa - the original card schemes that formed it. The EMV Contactless Specifications apply to transactions employing proximity NFC payment devices. These devices require transactions to be carried out by waving or tapping a terminal allowed by EMV Contactless. Comparable to contact chip cards, they

also offer cryptographic functions for more secure transactions than conventional magnetic stripe cards [26].

Hence, such specification provides an international standard adopted by major credit card and smartphone companies to use in global commerce [27]. As previously stated, contactless transactions are established with contactless credit or debit plastic cards and also with NFC-enabled electronic devices, like smartphones, smartwatches, and other wearable devices, which have embedded and virtualised cards. For instance, contactless payment mobile applications involve Apple Pay, Android Pay, and Google Wallet, and also transit cards.

2.3.3 Contactless Technologies

The collection of technologies originally developed to help identifying objects is frequently described as contactless technologies. Over the times the progress of before-mentioned technologies facilitated the emerging of new applications, like access control, inventory management, data exchange, contactless payments and toll collections. Now, contactless technology is offered in various formats, for example, smart cards, tags and smartphones.

Radio Frequency Identification (RFID)

One of the most popular technology and quickly growing interest in scientific and commercial sectors is Radio-Frequency Identification (RFID), a well-known wireless standardised technology, as it is ubiquitous in the industry and daily lives.

RFID is a versatile technology, and it is reasonable to think that many applications to exploit RFID full potential have not yet been completely realised. Examples of its recent employments are medical and retail inventory, asset management, operational configuration, animal and object identification, people tracking, ticketing, payments, passports, car keys, and numerous others [28, 29]. This technology can be seen as a new version of the barcodes, from which RFID offers an upgrade, due to non-line-of-sight recognition [29].

Riaz et al. describe an RFID system as a combination of an RFID reader, an RFID tag and a computer to manage the information [29], a visual example can be observed in Figure 2.3. According to Wadii et al., the system interaction combines the following actions:

1. The reader starts by emitting a radio wave signal, which can be detected by one or more tags located in the reader's range;
2. The reader then waits for a feedback signal to be sent by one of the tags, and so establishing a communication between the reader and the tag;

3. Finally, after a demodulating procedure from the reader, the host computer (or a terminal) receive the data for further processing [30].

Figure 2.4 depicts a simplified version concerning the components of an RFID reader, which consist of a controller unit, a Radio Frequency (RF) transceiver module (transmitter and receiver), an antenna, and lastly, an interface that allows connecting with a computer [31, 29].

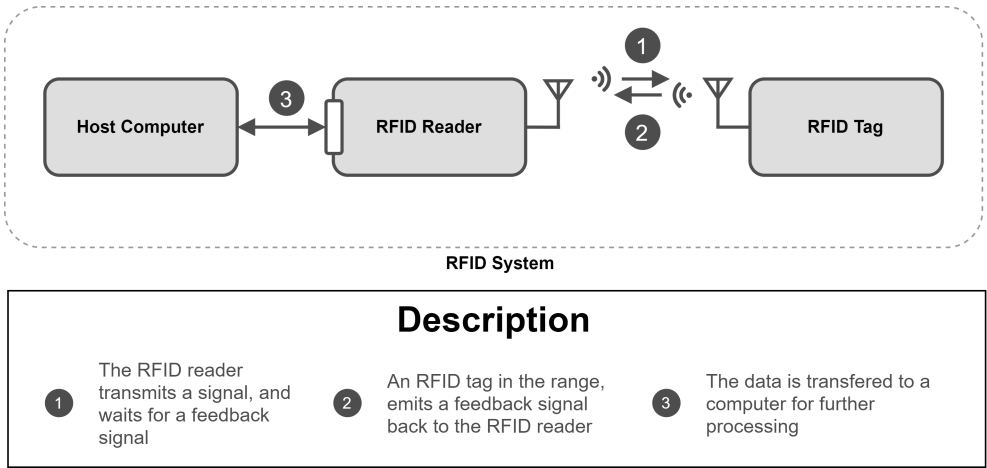


Figure 2.3: Example of an RFID system

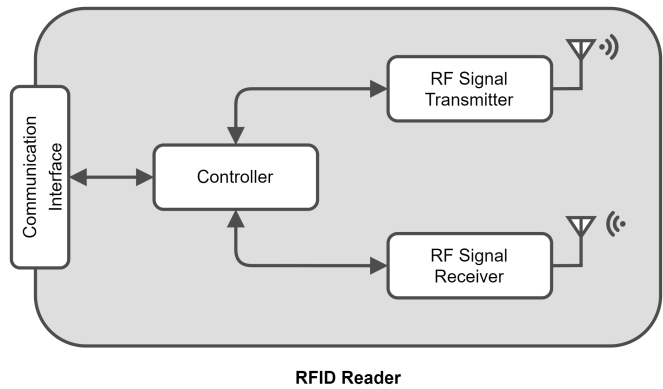
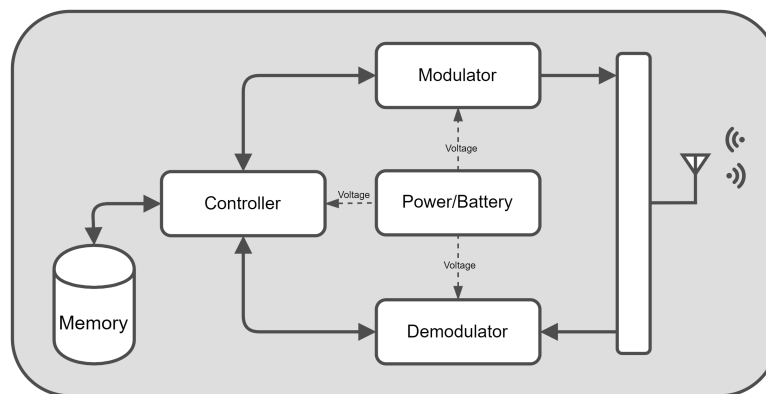


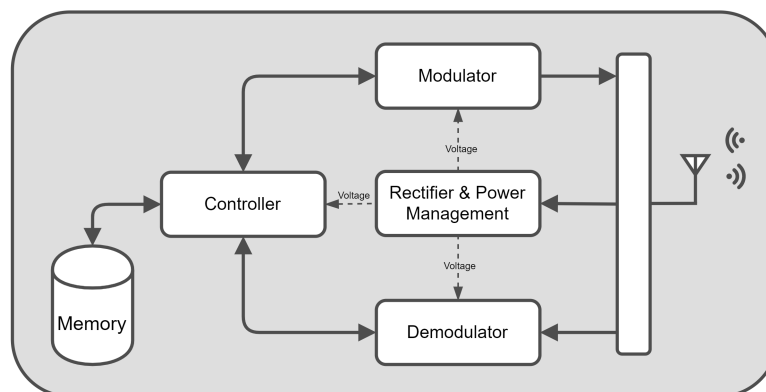
Figure 2.4: Architecture of an RFID reader

RFID readers are continuously transmitting radio waves to allow RFID tags, within the range, to identify them and emit a feedback signal back to them. Figure 2.5 presents a generic architecture of RFID tags, which is composed of an antenna and a transponder (transmitter/responder) capable of modulating and demodulating radio waves [31], i.e., translating an analogue information into a digital data by radio link [30]. There are several forms of RFID. The majority of the authors consider it reasonable to classify the tags into three classes – active, passive, and semi-passive.

- **Active RFID Tags** – This class of tags includes a power source, either by an attached powered substructure or utilising the energy stored in an integrated battery, which allows the transmission of the radio waves. Consequently, causing higher costs in the production of such tags [30]. Figure 2.5.A intends to represent a simpler architecture of these class of tags. An active tag lifetime is bounded by the stored energy and by the number of reading operations the device supports [31].
- **Passive RFID Tags** – This is the most economical class of RFID tags since it doesn't require batteries or maintenance, majorly the reason for its long operational lifetime [30, 31]. In fact, not having a power source allows this type of tags to be compact enough to fit an adhesive label. Figure 2.5.B depicts a simplified version of passive tags.
- **Semi-Passive RFID Tags** – An intermedial form of RFID tags between active and passive tags, which means these tags emit data employing energy from a battery and or generate it from the radio waves broadcasted by RFID readers, similar to passive tags [30].



A) Active RFID Tag



B) Passive RFID Tag

Figure 2.5: Architecture of an RFID tag

For RFID readers to communicate with passive tags, they must power them first, and that is the reason these tags have a rectifier and a power management module. The voltage developed across the antenna terminal powers up the tag integrated chip and send back information to the reader by varying the input impedance and modulating back-scattered signals [29]. As attested by Patel, there are two distinct RFID design approaches for transmitting power from the reader to the tag depending on the range, which are magnetic induction for near-field coupling and electromagnetic for far-field coupling, respectively [31].

Due to the vast number of RFID implementations in the modern world, and the need to meet the specifications of the system to operate correctly and accomplish its purpose, various frequency ranges have been used. The authorised frequencies of operation differ throughout the globe, leading to the existence of numerous variations and different standards, which Table 2.3 lists and summarises.

Wadii et al. asserted the contribution of the International Standard Organisation (ISO) in establishing technical and application standards, which allows for a high degree of interoperability and interchangeability [30]. Specifically the ISO/IEC 14443:2018.

Table 2.3: Comparison of the main characteristics of the various RFID frequencies of operation

	Frequency Range	Read Range	Coupling Type	Existing Standards	Applications
Low Frequency (LF)	125-134 kHz	~10 cm	Magnetic Near-Field	ISO 11784/85 ISO 14223 ISO/IEC 18000-2	- Smart cards; - Ticketing; - Access Control; - Animal Tagging.
High Frequency (HF)	13.56 MHz	~1 m	Magnetic Near-Field	ISO/IEC 18000-3.1 ISO/IEC 15693 ISO/IEC 14443-A/B	- Inventory Management (Small Scale); - Supply Chains; - Anti-theft Systems; - Libraries.
Ultra High Frequency (UHF)	900 MHz	~2-20 m	Electromagnetic Far-Field	EPC C0, C1, C1G2 ISO/IEC 18000-6	- Vehicle Identification; - Access Control; - Supply Chain; - Inventory Management (Big Scale).
Microwaves	2.4 GHz	~10 m	Electromagnetic Far-Field	ISO/IEC 18000-4	- Vehicle Identification; - Road Toll; - Access Control; - Security; - Supply Chain; - Inventory Management (Big Scale).

Near-Field Communication (NFC)

Contactless technologies like Near Field Communication (NFC) enable wireless communication between compatible devices for interchanging data over short distances (up to 10 cm), which ISO/IEC 18092 and ECMA-340 standardised [30, 32, 33]. In the opinion of Brumerickova et al., this technology is an easy and secure either-way communication, very similar to the RFID [33]. Wadii et al. agree and point out the fact of the two-way

communication cannot be simultaneously in time, and adds that “NFC is a technology derived from RFID”, hence an extension of the ISO/IEC 14443 [30].

A broad spectrum of applications employs NFC in the core of their implementations [33]. Following the integration of this technology in smartphones, NFC has established itself [30] in several forms, such as access control, product verification/authentication, coupling cards (coupons or loyalty cards), pairing-devices, embedded experiences, mobile applications, payments, or even providing for exclusive content, among many others.

Mainly, mobile payment applications are the driving force behind NFC technology, which has enabled its use in contactless mobile payments [30], with a single tap of an NFC-equipped smartphone against a point-of-sale (POS). This easiness of usage has prompted NFC on mobile to be the most used and most supported technology in the contactless payment at point-of-sale.

Various smartphones' companies equipped and continue to equip their devices with NFC technology. In the year of 2014, 444 million devices had NFC technology integrated, and an estimative predicted that by 2020, the number of such devices would be 2.2 billion [30]. At present, billions of smartphones are equipped with NFC modules, which proves to be a strong foundation to enlarge its scope of applications in human activities [34].

The novel design concept endows NFC chips the ability to harvest energy. Such chips collect the energy produced by the magnetic field generated by the reader and provide an analogue voltage output to power and control external electronics [34]. Concerning the security issues, NFC applications are hosted and governed in the secure element of smartphones and operate with one of four main models: 1) Device-centric, 2) Host Card Emulation, 3) SD-centric, and 4) SIM-centric. Wadii et al. considered the latest model to be noteworthy in terms of portability and security [30]. NFC applications, like the ones mentioned earlier, frequently have three operation modes:

- **Card Emulation Mode** – It's also known as passive mode, which is similar to a contactless smart card. In this case, the card must be virtualised within a mobile app, which allows tapping the smartphone against a reader, exactly like a plastic contactless card. This mode regularly used in payments, ticketing, couponing, access control, among others.
- **Read/Write Tags Mode** – The use of this mode is identical to a terminal capable of reading real NFC cards. There are now Android mobile libraries facilitating interfaces for reading and writing in various NFC tags. Examples of this read/write mode are the case of electronic labels in bus stops, monuments, products, business cards.
- **Peer-to-Peer Mode** – This mode is suitable for transferring data between two mobile devices, for instance, permits NFC-enabled devices to communicate and ex-

change information with contactless smart cards, as well as other devices, such as wearable devices.

Comparison of Contactless Technologies

Table 2.4: Comparison of contactless technologies (HF RFID vs. NFC vs. Bluetooth)

Characteristics	HF RFID	NFC	Bluetooth
Reader Cost	High	Low (Smartphones)	Low (Smartphones)
Frequency Range	13.56 MHz	13.56 MHz	2.4 - 2.48 GHz
Read Range	<1.5 m	1 - 2 cm for proximity cards 0.5 m for vicinity cards	10 - 100 m
International Frequency Regulation	No, by regions	Yes	Yes
Standards	ISO/IEC 14443, ISO/IEC 18000-2, ISO 11784/85	ISO/IEC 18092, ECMA-340	IEEE Std 802.15.1
Energy Harvesting	Yes	Yes	No
Tag Type	Passive	Passive	-
Tag Price	High	Low	High
Memory Capacity	<2 KB	<8 KB	Several KiloBytes
Applications	Ticketing Payments Data Transfer	Payments Pairing Devices Embedded Experiences Access Control Product Authentication Exclusive Content	Data Transfer Pairing Devices Electronic Devices Gaming Equipment Speakers Wireless Headphones

At the present moment, the number of wearable devices for information transmission is continuously growing, with all different applications one may think. Wireless communication technologies, like RFID and Bluetooth, have been at the heart of before-mentioned electronics. Amongst them, the adoption of NFC in compliance with the RFID standards has attracted considerable interest, primarily due to its high reliability, smooth operation, and cost of production [34].

Table 2.4 contrasts the key characteristics of various types of wireless and contactless systems, such as high-frequency RFID, NFC and Bluetooth.

High-frequency (HF) RFID systems promoted in the market have a large range of commercial application, for instance, payments, ticketing, data transfer, supply chains, object tracking, and many others. Passive HF RFID tags have functional capabilities for short operation distance and lower-cost than low-frequency (LF) RFID tags. Nevertheless, HF RFID readers are costly relative to LF RFID and NFC reader, which contributes

to difficulties in profiting from consumer goods [34]. The price of RFID systems depends fundamentally on the tags, which is the expense of the chips. Several attempts have also been made to improve chipless RFID, and some sensors based on chipless RFID technologies have been produced [34]. Despite the easiness of establishing a contactless payment ecosystem with RFID, the existing smartphones do not support the RFID frequency band [30].

NFC tags are capable of harvesting energy, which enables the development of low-cost and green energy wearable devices. In the meantime, the proper design, materials and manufacturing of NFC antennas will boost its performance [34]. As a consequence, NFC technology seems to be more promising in terms of the potential use cases [30]. For example, a new encouraging technology of mobile payments relies upon NFC-enabled devices that transform smartphones into mobile credit cards [35]. Furthermore, the progress of smartphones facilitates the widespread application of NFC technology, which empowers users to integrate their daily-use loyalty cards, credit cards, with a simple tap of their smartphone mainly to NFC high security. Other advantages, like admittance control, access to exclusive content, or even product authentication, as well as embedded experiences, are some of the examples of the usage and capabilities NFC has to offer, by promoting and improving human activities. In terms of costs, NFC readers are normally more economical than other RFID devices [34]. So far as available power is concerned, NFC technology may use batteries to relay energy, or when in passive mode, NFC tags will collect energy from readers [34].

In comparison to the pair of wireless networking systems mentioned above, Bluetooth has a more attractive reading range than NFC, and can reach 10–100 m, apart from being capable of low-power consumption [34]. Nevertheless, contrary to NFC, Bluetooth technology has to be powered by a battery because it has no energy storage capability [34]. Similar to NFC, and although the costs, Bluetooth can be found in smartphones, contrasting the RFID technology.

2.3.4 Contactless Technologies in Transit

In the past, transport operators incorporated contactless solutions as part of their proprietary fare collection system to diminish the time wasted at gates, which allow passengers to enjoy of secure and easy payments, as well as seamless and convenient journeys. The popularisation of contactless smart cards that similarly function as stored-value cards continue increasing worldwide amongst transit operators.

Mainly, the transit agencies' interest in using contactless smart cards results as these cards offer a secure method of user validation and fare payment. Paradela suggests such cards have advantages like high portability, ease of use, and elevated security levels [36]. Besides Pelletier et al. recognised that smart cards improve the quality of the data, provide transit agencies with a modern look, and present new opportunities for innovative and

flexible fare structuring [37].

Contactless smart cards present a convenient means of storing and validate electronic tickets, also known as a contract in public transport. These cards may hold a variety of contracts, depending on the card's specifications and data storage, as well as the data model employed [36]. The cards adopted by the transit agencies are robust and sophisticated when compared with smart cards that do not offer any embedded security mechanism.

Commonly, this type of card produced with plastic is more resistant than paper tickets, and more secure than magnetic cards, since it has a microprocessor embedded to enable the card to operate a specific communication protocol, e.g. the ISO/IEC 14443. These cards have secret keys stored, that solely the card has access, which permits for authentication mechanisms that guarantee the authenticity of the data written [36]. Examples of before-mentioned cards might be variations of Calypso, or MIFARE, MIFARE DESFire, amongst several others.

In conclusion, contactless payment systems that employ debit or credit smart cards are an essential factor to include in the transit industry's near future. As it evolves and ensures the travellers' pleasanter experience, as well as simplify the transports' AFC systems, and hence rising their revenue.

2.3.5 Contactless Payments in Transit

EMV Contactless Specifications for Payment Systems

The purpose of the EMV Specifications are to facilitate the worldwide interoperability and acceptance of secure payment transactions. Notice the importance of following specifications to this project:

- "*Contactless Specifications for Payment Systems*", namely, Book A, Book B, Book C-2 and Book C-3, that refer to transactions using proximity NFC payment devices.
- "*Integrated Circuit Card Specifications for Payment Systems*", that refers to the EMV contact chip specifications defining how financial transactions are conducted using contact chip cards.

2.4 Related Work

The media and societies frequently employ the term smart city, shifting the cities' attention to own the status of a smart city. Modern cities are developing very quickly, raising numerous problems; therefore, most of them focus on smart solutions to help the city with the contemporary issues, to offer a higher degree in quality and comfort of life. Although there's not a correct definition of the term smart city, the scientific community agrees on the vital core of creating a more efficient and sustainable environment for humankind.

As aforementioned, one of the major concerns of urban centres includes public transport, which smart mobility solutions already partially solved. Thus, there is a strong interdependence of mass transport with ICT components, like cloud computing, software, hardware, raw data, transactions, communication and internet access, that can all be combined into one system. A smart mobility definition states the following:

“Smart mobility is best described as approaches that reduce congestion and foster faster, greener and cheaper transportation options. Most smart mobility systems use data collected from a variety of sources about mobility patterns in order to help optimize traffic conditions in a holistic manner. Smart mobility systems include mass transit systems as well as individual mobility systems.”

— Commission on Science and Technology for Development [38]

For all the previous reasons, nowadays, passengers are the core of public transport operators' attention. Transit operators aim to assure good reception, offer more comfort and security, which might include personalised services to their customers. In order to fulfil such objectives, transports require detailed knowledge of the passengers' preferences and patterns, as well as evolve their legacy systems, to ensure a high quality of service.

Across the globe, various ticketing solutions arise, which alternate in various factors, such as convenience, adoption, features, technologies employed, and others. Several cities implemented electronic ticketing systems in the transport industry, described next are Hong Kong, Lisbon, London, Porto, and Queensland, in alphabetic order. The selection of these cities was based on the analyse of distinct researches and scientific articles, as well as other matters, subsequently explained.

Firstly, contactless integrated circuits (IC) cards, namely the Octopus Card, used in Hong Kong since 1997 is becoming more common. Multiple scientific articles dated from 2009, mention the Octopus Card as a case of study, for its vast applications in the economy, and not merely in the transports industry, causing Hong Kong to be one of the cities selected and so described below [39, 40, 41, 4, 42, 43].

Secondly, it's London Oyster Card, with EMV bank cards acceptance and integration, due to the similarity with this project, and for being one of the pioneers in such matters [39, 40, 41, 4, 19, 6]. Aside from that, London is one of the world's top smart cities, as considered by Dudycz and Piątkowski in "Smart mobility solutions in public transport based on analysis chosen smart cities" [2]. In the article, Singapore, San Francisco, and London smart mobility solutions are compared, as these cities were considered to Dudycz and Piątkowski the top three smart cities from each region, in descending order.

Thirdly, it's Queensland with the TransLink's Go cards, which allow commuters to pay for the ride using debit or credit card. Despite not being a well-known example, TransLink is mentioned as one of the success stories around the world in a recent article

of 2018, "Account-Based Ticketing: The Benefits and Drivers for Transit Operators" by Zamer [19].

Lastly, Lisbon and Porto, with Lisboa Viva and Andante Cards, respectively, for its national interest and importance. Plus, it is in these cities where the project aims to be later embedded.

Another examples are viable systems worth to highlight and describe such as the OV-Chipkaart used in the entire Netherlands [4], the eZ-Link in Singapore [41], the Rejsekort in Denmark [42], Chicago Card Plus/I-Go Card in Chicago [40], Técély Card in Lyon [40], the PASMO and Suica Cards from Tokyo [40], the Yikatong Card in Beijing [19], amongst many others.

2.4.1 Octopus

Southeast China, moreover Hong Kong launched in 1977 the contactless stored value card Octopus to support a multi-modal ticketing solution between Shenzhen, Hong Kong and Macau. This card presents itself as a simple, safe and secure way of paying. Initially emerged across public transport systems and quickly continued to grow to other industries [44]. Nowadays, 99% of people in Hong Kong use Octopus cards to travel, shop and at restaurants without the need of cash.

According to Octopus Cards Limited website, several types of Octopus cards exist, e.g., On-Loan Octopus, Sold Octopus, Bank Co-Brand Octopus, Cross Border Octopus, Octopus Mobile SIM (a mobile phone SIM card with embedded Octopus functions) and Smart Octopus in Samsung Pay [44]. The On-Load Octopus have profile schemes, for children, adult and elder, with anonymous or personalised alternatives.

Octopus is available in many formats, like cards, devices such as watches, key rings, ornaments, and others. Furthermore, Octopus usage range broadly, particularly for:

- Simple fare payments on public transport;
- Small-value payments in the retail sector;
- Payments at government tolled tunnels;
- Admission and payment for parking;
- Access control for residential and commercial buildings;
- Shop and pay at designated online merchants;
- Purchase and save e-tickets for specific merchants;
- Execute bill payments at specific merchants and set a monthly reminder to avoid payment delays;
- Perform payments of specific government bills or service fees;
- Make donations to specific charity organisations.

The last 5 services are exclusively for the Octopus App, which requires an associated Octopus card, O! ePay account, Octopus Mobile SIM or Smart Octopus. Moreover, pay-

ments with merely one tap are possible by using an NFC-enabled Android mobile device or an Octopus Mobile Reader for iOS smartphones, or directly from O! ePay account, Octopus Mobile SIM and Smart Octopus. Octopus App offers many other benefits for its users [44].

Top-ups are mandatory to enable the transactions to flow. Costumers' might use the Octopus App, Kiosks which offers credit/debit card or cash payments, and Coin Carts circulate across the region to collect coins and exchange them for banknotes or topping-up the Octopus account [44]. Multiple financial institutions offer the Automatic Add Value Service (AAVS) to ensure consumers never have their Octopus account under HK\$0, for that, costumers allow the AAVS to top-up with a predefined amount of HK\$150, HK\$250 and HK\$500 [44].

2.4.2 VIVA

In 2019, Lisbon re-implemented multi-modal packages to promote the accessibility of the periphery citizens to the heart of the city and also to encourage the adoption of public transports [45]. This strategy employs the already existing proprietary electronic cards, i.e., the contactless stored value cards, named as *Lisboa VIVA*. The passengers can serve of underground, bus, train, ferryboat, car-sharing, and parking [45]. Prices vary according to the users' profile, that can be children, student, adult, or senior.

Lisboa VIVA has various available packages to simplify commuters' life. For example, single and return tickets, 24 hours or monthly packages, and pay-as-you-go [45]. The packages can combine multiple operators or aggregate them. Hence, supporting occasional and frequent passengers. Additionally, in the early of 2019, a simplified post-paid solution emerged, named *VIVA Go* which grants passengers the possibility of associating a debit card with the *Lisboa VIVA* card, to enable automatic payments after some days of usage with the adherent operators [45].

Furthermore, the purchase process has slight variances for single tickets, packages and pay-as-you-go. Passengers have two options to purchase single tickets; the first option is a paper ticket acquired at the driver or a station, the other option is by topping-up their cards with trips or money at ticket vending machines and particular stores [45]. Contrastingly, to acquire packages, it is mandatory to have the *Lisboa VIVA* card, in order to store, use and validate the purchased package [45]. The same applies to pay-as-you-go; this option works in a similar way to a prepaid card that stores the balance and discounts it every time the passengers travel and validate their cards.

Even though Lisbon's ticketing solution offers multi-modal packages according to the passengers' profile and frequency of use, there are some inconveniences. For instances the ticket receipt in vigour must be kept in case of loss or damage of the card, another example is the first time purchasing a package has to be in ticketing vending machines, and only then the customer can charge the card in an automated teller machines (ATM) or

using the website, but for that, the user needs a card reader [45].

2.4.3 Oyster

Partially identical to Lisbon is London with its stored value contactless card for a multi-modal ticketing system labelled Oyster card [46], yet Transport for London (TfL) incorporated additional innovations over the years. Moreover, TfL offers six distinct ticket options [46], namely:

- *Passes* with daily, weekly, monthly or annual packages;
- *Day Travelcards* for a single passenger or groups of 10 or larger, where travels might occur at any time of the day or during off-peak hours;
- *Season Travelcards* that might be weekly, monthly, 3 months, 6 months, an odd period or annual;
- *Single and Return Tickets printed in paper*;
- *Pay-as-you-go*, the cards hold an amount discountable as passengers start or end the trip by validating it; automatic top-up might be enabled thus passengers never run out of credit, by doing so when balance is under £20, the *Oyster* card is automatically topped-up with either £20 or £40 from the users' bank account;
- *Contactless and Oyster Account*, a bank card, mobile payment and some prepaid cards offer passengers the convenience of post-paid seamless travel; the account allows users to check their payment and journey history, receive alerts, collect refunds when existing, settle unpaid fares, and add contactless bank cards.

The purchase of tickets is available online either emitting paper tickets or using contactless cards, devices or the oyster card, which is possible at verified stores, at stations, ticket vending machines or in the mobile application [46].

2.4.4 Andante

Comparable with *Lisbon VIVA* is *Andante* in Porto, also a multi-modal ticketing solution supported by a contactless stored value card, that likewise offers single tickets, pay-as-you-go and monthly packages [47]. The *modus operandi*, such as the purchase process, user profiles scheme, single and multi-modal packages [47], amongst others, is quite similar to *Lisboa VIVA* too.

Porto's ticketing solution outshines Lisbon's by its recently developed mobile ticketing application, entitled *Anda*. The mobile application developed by the group of companies Intermodal Transports of Porto (TIP), the Faculty of Engineering of the University of Porto (FEUP), and technology companies, allows users to ride buses, light rail and heavy-rail trains in the metropolitan area of Porto only using anything but their smartphone [48].

As stated by Meireles de Amorim et al., *Anda* is based on check-in/be-out scheme and operates with NFC, Bluetooth and GPS. A trip starts within the application when the passenger taps the mobile phone on an NFC-enabled validator. Throughout the trip, the smartphone interacts with BLE beacons installed in buses, metro, and train stations by Bluetooth, as to locate the passenger along with the transport network [48]. This solution not only compels the dematerialisation of public transport tickets but also added a post-paid billing method, which optimises the customer's monthly tariff. Hence, the passengers' usage determines the price to pay, so invoices may denote monthly passes or single tickets, whichever is the most economical to customer.

2.4.5 Go

In South East Queensland, the TransLink is the responsible transit operator of the region, which associates several transportation means and provides multi-modal ticketing solutions [49], similar to the cities aforementioned. The favoured option is, like the others, a contactless stored value card referenced *Go*, and profiles schemes also exist [49].

Despite paper-wastage, paper tickets are still standard for buses, trains and ferries. The tickets are valid over 2 hours across the region and can be purchased on board buses and ferries using cash, or at ticket offices and ticket vending machines. Another option is the *Go* card that admits users to top-up before travelling; while on-boarding passengers must tap-on and tap-off at the end, so the *Go* card can calculate how many zones the journey included and then deduct the correct fare from the card's balance.

State of Queensland recommends registering the card online or by phone since passengers experience multiple advantages [49]. For instance:

- Enable online top-up or by phone;
- Grant automatically top-up of a preferred amount when the balance is lesser than \$5 directly from a credit or debit card, identical to London's auto top-up;
- Secure and protect the card's balance against damage, loss or theft considering users can block the card immediately through the phone or online;
- Request for a refund or a balance transaction between cards;
- Receive SMS or e-mail notifications;
- Check the card's expiry date.

2.5 Discussion

Multiple citizens of the world continue to use their private cars to commute to work, although the various public transport networks available at present. Hence, the quality and accessibility of transport services are crucial to passengers' quality of life. For that reason, improving and expanding public transport simplifies people's lives and enhance

Table 2.5: Comparison of features of worldwide electronic ticketing solutions

Features	Octopus	VIVA	Oyster	Andante	Go
Multi-modal Ticketing	•	•	•	•	•
Paper Tickets	•	•	•	•	•
Stored-value Cards	•	•	•	•	•
Contactless Debit/credit Cards			•		
Pay-as-you-go	•	•	•	•	•
Ticketing Packages		•	•	•	
Mandatory Top-up	•	•	•	•	•
Automatic Top-up	•		•		•
Post-paid Solution		•	•		
Mobile Application	•		•	•	
Multi-purposes	•		•		

the attractiveness of sustainable travel over private car utilisation [50]. And, in the long term, cities can commit to creating a fairer, greener, healthier, and more prosperous city.

Hong Kong, Lisbon, London, Porto and Queensland have satisfying examples of electronic ticketing solutions developed for transports, which this section intends to discuss below.

Each solution offers multi-modal ticketing, from which Go and Octopus are remarkably better, by connecting an entire state of Australia, and three major cities from China, respectively — contrasting to VIVA, Oyster and Andante, which only provide transport from the periphery to the city centre.

Concerning the tickets, either stored-value cards or paper tickets, are a feature shared by all five solutions. For that reason, top-ups are mandatory to travel, and pay-as-you-go travel style is amongst the top forms of riding. VIVA, Oyster and Andante offer ticket packages, which can be daily, weekly or monthly, and have an attractive value, being the preferred option for passengers that travel frequently. Due to the fact, of having stored-value cards with mandatory top-ups, Octopus, Oyster and Go enabled automatic top-ups for improved convenience when the card's balance is beneath a certain amount.

Only VIVA and Oyster facilitate post-paid solutions that allow passengers to travel for a specific interval and being invoiced later. London Oyster does it better since enabled customers the option of using their contactless debit, credit or prepaid cards to pay the journey fare. Additionally, the Transport for London introduced caps that allow passengers to pay a fair amount for their journeys, e.g., when one performs more trips than the monthly package fare, then only that package is charged. VIVA Go, on the other hand, associates the debit or credit card of the passenger to the transport card Lisboa VIVA, and charges by journey at the end of the week, or a couple of days, thus not optimising the cost for its users.

Regarding mobile applications for both Android and IOS, VIVA is delayed when com-

pared to Octopus, Oyster, Go, and Andante, because it doesn't provide its users with one. The core of such applications is allowing to integrate information, booking, payment, and others, nevertheless solely Anda App (from Andante) and Octopus App privilege passengers to tap their smartphones to travel.

Octopus, which is one of the oldest solutions, is considerably ahead in progress when compared with the remaining systems. Mainly, the usage of Octopus cards is extensive, for instance, allows for the payment of goods and services, government tolled tunnels, bills and fees, enables access control, admission and payment for parking, amongst others.

Despite Octopus advancement, Oyster incorporates the entire features granting Londoners' to enjoy of much pleasanter travelling experience, while using their contactless debit or credit cards with post-paid billing, not discharging them from still getting the best fare. Nevertheless, different options are yet available for passengers that do not wish to utilise their debit or credit cards but can still have a seamless and comfortable experience.

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